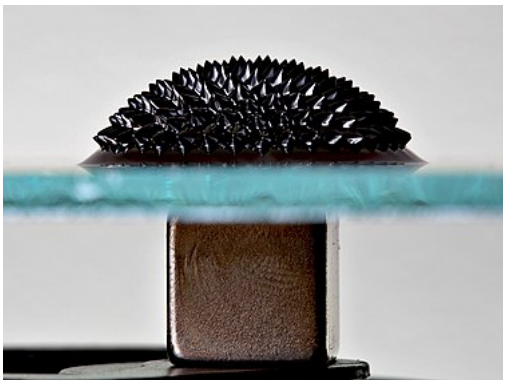
Rare-earth magnet

A **rare-earth magnet** is a strong permanent magnet made from alloys of rare-earth elements. Developed in the 1970s and 1980s, rare-earth magnets are the strongest type of permanent magnets made, producing significantly stronger magnetic fields than other types such as ferrite or alnico magnets. The magnetic field typically produced by rare-earth magnets can exceed 1.2 teslas, whereas ferrite or ceramic magnets typically exhibit fields of 0.5 to 1 tesla.



Ferrofluid on glass, with a rare-earth magnet underneath

There are two types: neodymium magnets and samarium–cobalt magnets. Rare-earth magnets are extremely brittle and also vulnerable to corrosion, so they are usually plated or coated to protect them from breaking, chipping, or crumbling into powder.

The development of rare-earth magnets began around 1966, when K. J. Strnat and G. Hoffer of the US Air Force Materials Laboratory discovered that an alloy of yttrium and cobalt, YCo_5, had by far the largest magnetic anisotropy constant of any material then known.[1][2]

The term "rare earth" can be misleading, as some of these metals can be as abundant in the Earth's crust as tin or lead,[3] but rare earth ores do not exist in seams (like coal or copper), so in any given cubic kilometre of crust they are "rare".[4][5] China has the highest production[6] but China imports significant amounts of REE ore from Myanmar. Some countries classify rare earth metals as strategically important,[7] and Chinese export restrictions on these materials have led other countries, including the United States, to initiate research programs to develop strong magnets that do not require rare earth metals.[8]

Properties

Neodymium magnets (small cylinders) lifting steel balls. As shown here, rare-earth magnets can easily lift thousands of times their own weight.

The rare-earth (lanthanide) elements are metals that are ferromagnetic, meaning that like iron they can be magnetized to become permanent magnets, but their Curie temperatures (the temperature above which their ferromagnetism disappears) are below room temperature, so in pure form their magnetism only appears at low temperatures. However, they form compounds with the transition metals such as iron, nickel, and cobalt, and some of these compounds have Curie temperatures well above room temperature. Rare-earth magnets are made from these compounds.

The greater strength of rare-earth magnets is mostly due to two factors:

- Firstly, their crystalline structures have very high magnetic anisotropy. This means that a crystal of the material preferentially magnetizes along a specific crystal axis but is very difficult to magnetize in other directions. Like other magnets, rare-earth magnets are composed of microcrystalline grains, which are aligned in a powerful magnetic field during manufacture, so their magnetic axes all point in the same direction. The resistance of the crystal lattice to turning its direction of magnetization gives these compounds a very high

magnetic coercivity (resistance to being demagnetized), so that the strong demagnetizing field within the finished magnet does not reduce the material's magnetization.

- Secondly, atoms of rare-earth elements can have high magnetic moments. Their orbital electron structures contain many unpaired electrons; in other elements, almost all of the electrons exist in pairs with opposite spins, so their magnetic fields cancel out, but in rare-earths, there is much less magnetic cancellation. This is a consequence of incomplete filling of the f-shell, which can contain up to 7 unpaired electrons. In a magnet, it is the unpaired electrons, aligned so they spin in the same direction, which generate the magnetic field. This gives the materials high remanence (saturation magnetization J_s). The maximal energy density $B{\cdot}H_{max}$ is proportional to J_s^2, so these materials have the potential for storing large amounts of magnetic energy. The magnetic energy product $B{\cdot}H_{max}$ of neodymium magnets is about 18 times greater than "ordinary" magnets by volume. This allows rare-earth magnets to be smaller than other magnets with the same field strength.

Some important properties used to compare permanent magnets are: remanence (B_r), which measures the strength of the magnetic field; coercivity (H_{ci}), the material's resistance to becoming demagnetized; energy product ($B{\cdot}H_{max}$), the density of magnetic energy; and Curie temperature (T_C), the temperature at which the material loses its magnetism. Rare-earth magnets have higher remanence, much higher coercivity and energy product, but (for neodymium) lower Curie temperature than other types. The table below compares the magnetic performance of the two types of rare-earth magnets, neodymium ($Nd_2Fe_{14}B$) and samarium–cobalt ($SmCo_5$), with other types of permanent magnets.

Material	Preparation	B_r (T)	H_{ci} (kA/m)	$B{\cdot}H_{max}$ (kJ/m^3)	T_C (°C)
$Nd_2Fe_{14}B$	sintered	1.0–1.4	750–2000	200–440	310–400
$Nd_2Fe_{14}B$	bonded	0.6–0.7	600–1200	60–100	310–400
$SmCo_5$	sintered	0.8–1.1	600–2000	120–200	720
$Sm(Co,Fe,Cu,Zr)_7$	sintered	0.9–1.15	450–1300	150–240	800
Alnico	sintered	0.6–1.4	275	10–88	700–860
Sr-ferrite	sintered	0.2–0.4	100–300	10–40	450
Iron (Fe) bar magnet	annealed	?	800[9]	?	770[10][11][12]

Types

Samarium–cobalt

Samarium–cobalt magnets (chemical formula: $SmCo_5$), the first family of rare-earth magnets invented, are less used than neodymium magnets because of their higher cost and lower magnetic field strength. However, samarium–cobalt has a higher Curie temperature, creating a niche for these magnets in applications where high field strength is needed at high operating temperatures. They are highly resistant to oxidation, but sintered samarium–cobalt magnets are brittle and prone to chipping and cracking and may fracture when subjected to thermal shock.

Neodymium

Neodymium magnet with nickel plating mostly removed

Neodymium magnets, invented in the 1980s, are the strongest and most affordable type of rare-earth magnet. They are made of an alloy of neodymium, iron, and boron ($Nd_2Fe_{14}B$), sometimes abbreviated as NIB. Neodymium magnets are used in numerous applications requiring strong, compact permanent magnets, such as electric motors for cordless tools, hard disk drives, magnetic hold-downs, and jewellery clasps. They have the highest magnetic field strength and have a higher coercivity (which makes them magnetically stable), but they have a lower Curie temperature and are more vulnerable to oxidation than samarium–cobalt magnets.

Corrosion can cause unprotected magnets to spall off a surface layer or to crumble into a powder. Use of protective surface treatments such as gold, nickel, zinc, and tin plating and epoxy-resin coating can provide corrosion protection; the majority of neodymium magnets use nickel plating to provide a robust protection.

Originally, the high cost of these magnets limited their use to applications requiring compactness together with high field strength. Both the raw materials and the patent licenses were expensive. However, since the 1990s, NIB magnets have become steadily less expensive, and their lower cost has inspired new uses such as magnetic construction toys.

Applications

Neodymium magnet balls

Since their prices became competitive in the 1990s, neodymium magnets have been replacing alnico and ferrite magnets in the many applications in modern technology requiring powerful magnets. Their greater strength allows smaller and lighter magnets to be used for a given application.

Common applications of rare-earth magnets include:

- Computer hard disk drives
- Wind turbine generators
- speakers / headphones
- Bicycle dynamos
- MRI scanners
- Fishing reel brakes
- Permanent magnet motors in cordless tools
- High-performance AC servo motors
- Traction motors and integrated starter-generators in hybrid and electric vehicles
- Mechanically powered flashlights, employing rare earth magnets for generating electricity in a shaking motion or rotating (hand-crank-powered) motion

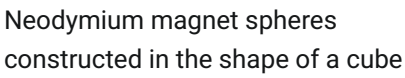
- Industrial uses such as maintaining product purity, equipment protection, and quality control
- Capture of fine metallic particles in lubricating oils (crankcases of internal combustion engines, also gearboxes and differentials), so as to keep said particles out of circulation, thereby rendering them unable to cause abrasive wear of moving machine parts

Other applications of rare-earth magnets include:

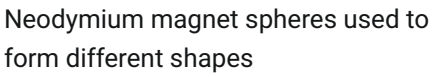
- Linear motors (used in maglev trains, etc.)
- Stop motion animation: as tie-downs when the use of traditional screw and nut tie-downs is impractical.
- Diamagnetic levitation experimentation, the study of magnetic field dynamics and superconductor levitation.
- Electrodynamic bearings
- Launched roller coaster technology found on roller coaster and other thrill rides.
- LED Throwies, small LEDs attached to a button cell battery and a small rare earth magnet, used as a form of non-destructive graffiti and temporary public art.
- Desk toys
- Electric guitar pickups
- Miniature figures, for which rare-earth magnets have gained popularity in the miniatures gaming community for their small size and relative strength assisting in basing and swapping weapons between models.

Hazards and legislation

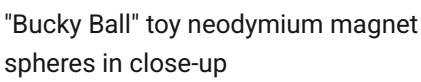
Two objects made of neodymium magnets. The right object has the close-packing of equal spheres.



Neodymium magnet spheres constructed in the shape of a cube



Neodymium magnet spheres used to form different shapes



"Bucky Ball" toy neodymium magnet spheres in close-up

The greater force exerted by rare-earth magnets creates hazards that are not seen with other types of magnet. Magnets larger than a few centimeters are strong enough to cause injuries to body parts pinched between two magnets or a magnet and a metal surface, even causing broken bones.[13] Magnets allowed to get too near each other can strike each other with enough force to chip and shatter the brittle material, and the flying chips can cause injuries. Starting in 2005, powerful magnets breaking off toys or from magnetic construction sets started causing injuries and deaths.[14] Young children who have swallowed several magnets have had a fold of the digestive tract pinched between the magnets, causing injury and in one case intestinal perforations, sepsis, and death.[15]

The swallowing of small magnets such as neodymium magnetic spheres can result in intestinal injury requiring surgery. The magnets attract each other through the walls of the stomach and intestine, perforating the bowel.[16][17] The U.S. Centers for Disease Control reported 33 cases as

of 2010 requiring surgery and one death.[18][19] The magnets have been swallowed by both toddlers and teens (who were using the magnets to pretend to have tongue piercings).[20]

North America

A voluntary standard for toys, permanently fusing strong magnets to prevent swallowing, and capping unconnected magnet strength, was adopted in 2007.[14] In 2009, a sudden growth in sales of magnetic desk toys for adults caused a surge in injuries, with emergency room visits estimated at 3,617 in 2012.[14] In response, the U.S. Consumer Product Safety Commission passed a rule in 2012 restricting rare-earth magnet size in consumer products, but it was vacated by a US federal court decision in November 2016, in a case brought by the one remaining manufacturer.[21] After the rule was nullified, the number of ingestion incidents in the country rose sharply, and is estimated to exceed 1,500 in 2019, leading the CPSC to advise children under the age of 14 to not use the magnets.[14]

In 2009 US company Maxfield & Oberton, maker of Buckyballs, decided to repackage sphere magnets and sell them as toys.[22] Buckyballs launched at New York International Gift Fair in 2009 and sold in the hundreds of thousands before the U.S. Consumer Product Safety Commission issued a recall on packaging labeled 13+.[23] According to the CPSC, 175,000 units had been sold to the public. Fewer than 50 were returned.[24] Buckyballs labeled "Keep Away From All Children" were not recalled. Subsequently, Maxfield & Oberton changed all mentions of "toy" to "desk toy", positioning the product as a stress-reliever for adults and restricted sales from stores that sold primarily children's products.[25]

In the United States, as a result of an estimated 2,900 emergency room visits between 2009 and 2013 due to either "ball-shaped" or "high-powered" magnets, or both, the U.S. Consumer Product Safety Commission (CPSC) has undergone rulemaking to attempt to restrict their sale.[26]

Further investigation by the CPSC published in 2012 found an increasing trend of magnet ingestion incidents in young children and teens since 2009. Incidents involving older children and teens were unintentional and the result of using the magnets to mimic body piercings such as tongue studs.[27] The commission cited hidden complications if more than one magnet becomes attached across tissue inside the body. Another recall was issued for Buckyballs in 2012 along with similar products marketed as toys in the US. Recalls and administrative complaints were filed against other similar US companies. Maxfield & Oberton refused the recall and continued selling their desktop toys. The company launched a political campaign against the CPSC, and Craig Zucker, the company's co-founder, debated the safety commission on FOX News.[28]

In June 2012, due to a letter by U.S. Senator Kirsten Gillibrand to U.S. Consumer Product Safety Commission Chairwoman Inez Tenenbaum,[29] the United States Consumer Product Safety Commission filed administrative complaints, attempting to ban the sale of Buckyballs[30] and Zen Magnets.[31] Zen Magnets LLC is the first company to ever receive this sort of complaint without record of injury.[32] In November 2012, Buckyballs announced that they had stopped production due to a CPSC lawsuit.[33]

In March 2016, Zen Magnets (a manufacturer of neodymium magnet spheres) won in a major 2014 court hearing concerning the danger posed by "defective" warning labels on their spherical magnets.[34] It was decided by a DC court[35] (CPSC Docket No: 12-2) that "Proper use of Zen Magnets and Neoballs creates no exposure to danger whatsoever."[36] As of January 2017, many brands of magnet spheres including Zen Magnets have resumed the sale of small neodymium magnet spheres following a successful appeal by Zen Magnets in the Tenth Circuit US Court of Appeals which vacated the 2012 CPSC regulation banning these products and thereby rendered the sale of small neodymium magnets once again legal in the United States.[37] It was the CPSC's first such loss in more than 30 years.[38]

A study published in the Journal of Pediatric Gastroenterology and Nutrition found a significant increase in magnet ingestions by children after 2017, including "a 5-fold increase in the escalation of care for multiple magnet ingestions".[39] On June 3, 2020, the CPSC submitted a "Petition Response Staff Briefing Package" to the commission, even after the petition was rescinded. It outlines a desire to conduct research in 2021 with a suggested rule proposal in 2022 for a vote.[40]

As of 2019, manufacturers are working on a similar voluntary standard at the ASTM.[41] On October 26, 2017, the CPSC filed an administrative complaint against Zen Magnets, alleging that the magnet sets contained product defects that created a substantial risk of injury to children,

declaring that "It is illegal under federal law for any person to sell, offer for sale, manufacture, distribute in commerce, or import into the United States any Zen Magnets and Neoballs."[42]

Sales of "certain products with small, powerful magnets" are prohibited in Canada since 2015.[43]

Oceania

In November 2012, following an interim ban in New South Wales,[44] a permanent ban on the sale of neodymium magnets went into effect throughout Australia.[45]

In January 2013, Consumer Affairs Minister Simon Bridges announced a ban on the import and sale of neodymium magnet sets in New Zealand, effective from January 24, 2013.[46]

Environmental impact

The European Union's ETN-Demeter project (European Training Network for the Design and Recycling of Rare-Earth Permanent Magnet Motors and Generators in Hybrid and Full Electric Vehicles)[47] is examining sustainable design of electric motors used in vehicles. They are, for example, designing electric motors in which the magnets can be easily removed for recycling the rare earth metals.

The European Union's European Research Council also awarded to Principal Investigator, Prof. Thomas Zemb, and co-Principal Investigator, Dr. Jean-Christophe P. Gabriel, an Advanced Research Grant for the project "Rare Earth Element reCYCling with Low harmful Emissions : REE-CYCLE", which aimed at finding new processes for the recycling of rare earth.[48]

Alternatives

The United States Department of Energy has identified a need to find substitutes for rare-earth metals in permanent-magnet technology and has begun funding such research. The Advanced Research Projects Agency-Energy (ARPA-E) has sponsored a Rare Earth Alternatives in Critical Technologies (REACT) program, to develop alternative materials. In 2011, ARPA-E awarded $31.6 million to fund Rare-Earth Substitute projects.[8]

See also

- Circular economy – Production model to minimise wastage and emissions

- Lanthanide – Trivalent metallic rare-earth elements
- Magnet fishing – Searching in outdoor waters for ferromagnetic objects
- Recycling – Converting waste materials into new products

References

1. Cullity, B. D.; Graham, C. D. (2008). *Introduction to Magnetic Materials* (https://books.google.com/books?id=ixAe4qIGEmwC&pg=PA489) . Wiley-IEEE. p. 489. ISBN 978-0-471-47741-9.
2. Lovelace, Alan M. (March–April 1971). "More Mileage Than Programmed From Military R&D" (https://web.archive.org/web/20130224105721/http://www.airpower.au.af.mil/airchronicles/aureview/1971/mar-apr/Lovelace.html) . *Air University Review*. **22** (3). US Air Force: 14–23. Archived from the original (http://www.airpower.au.af.mil/airchronicles/aureview/1971/mar-apr/Lovelace.html) on February 24, 2013. Retrieved July 4, 2012.
3. Bobber, R. J. (1981). "New Types of Transducers". *Underwater Acoustics and Signal Processing*. pp. 243–261. doi:10.1007/978-94-009-8447-9_20 (https://doi.org/10.1007%2F978-94-009-8447-9_20) . ISBN 978-94-009-8449-3.
4. McCaig, Malcolm (1977). *Permanent Magnets in Theory and Practice*. US: Wiley. p. 123. ISBN 0-7273-1604-4.
5. Sigel, Astrid; Helmut Sigel (2003). *The lanthanides and their interrelations with biosystems*. US: CRC Press. pp. v. ISBN 0-8247-4245-1.
6. Walsh, Bryan (March 13, 2012). "Raring to Fight: The U.S. Tangles with China over Rare-Earth Exports" (http://science.time.com/2012/03/13/raring-to-fight-the-u-s-tangles-with-china-over-rare-earth-exports/) . *Time Magazine*. Retrieved November 13, 2017.
7. Chu, Steven (2011). *Critical Materials Strategy* (https://archive.org/details/bub_gb_lFrj-IPPvmcC) . Diane Publishing. pp. 96 (https://archive.org/details/bub_gb_lFrj-IPPvmcC/page/n95) –98. ISBN 978-1437944181. "China rare earth magnets."
8. "Research Funding for Rare Earth Free Permanent Magnets" (https://web.archive.org/web/20131010052554/http://arpa-e.energy.gov/?q=arpa-e-programs%2Freact) . ARPA-E. Archived from the original (http://arpa-e.energy.gov/?q=arpa-e-programs%2Freact) on 10 October 2013. Retrieved 23 April 2013.
9. Introduction to Magnets and Magnetic Materials, David Jiles, Ames Laboratrories, US DoE, 1991
10. Beichner and Serway. Physics for Scientists & Engineers with Modern Physics. 5th ed. Orlando: Saunders College, 2000: 963

11. Curie Temperature." McGraw-Hill Encyclopedia of Science & Technology. 8th ed. 20 vols. N.P: McGraw-Hill, 1997

12. Hall, H.E and J.R. Hook. Solid State Physics. 2nd ed. Chichester: John Wiley & Sons Ltd, 1991: 226.

13. Swain, Frank (March 6, 2009). "How to remove a finger with two super magnets" (http://scienceblogs.com/sciencepunk/2009/03/06/how-to-remove-a-finger-with-tw/) . *The Sciencepunk Blog*. Seed Media Group LLC. Retrieved 2017-11-01.

14. "Number of children swallowing dangerous magnets surges as industry largely polices itself" (https://www.washingtonpost.com/business/economy/number-of-children-swallowing-dangerous-magnets-surges-as-industry-largely-polices-itself/2019/12/25/77327812-2295-11ea-86f3-3b5019d451db_story.html?arc404=true) . *The Washington Post*. 2019-12-26. Archived (https://web.archive.org/web/20230611150132/https://www.washingtonpost.com/business/economy/number-of-children-swallowing-dangerous-magnets-surges-as-industry-largely-polices-itself/2019/12/25/77327812-2295-11ea-86f3-3b5019d451db_story.html?arc404=true) from the original on 2023-06-11.

15. "Magnet Safety Alert" (https://www.cpsc.gov/PageFiles/112864/5221.pdf) (PDF). U.S. Consumer Product Safety Commission. Retrieved 20 July 2014.

16. Child has bowel surgery after swallowing magnetic balls (https://archive.today/20130411232117/http://www.thespec.com/news/local/article/901742--child-has-bowel-surgery-after-swallowing-magnetic-balls) , Hamilton Spectator, March 13, 2013.

17. Young kids can swallow magnets, seriously damage intestines, doctors warn (http://globalnews.ca/news/407458/young-kids-can-swallow-magnets-seriously-damage-intestines-doctors-warn/) Global News Toronto, March 12, 2013.

18. Brooks, Leonard J; Dunn, Paul (March 31, 2009). "Magnetic Toys Can Hurt" (https://books.google.com/books?id=9x5Yj3nApN4C&q=%22magnetic+toys%22&pg=PA33) . *Business & Professional Ethics for Directors, Executives & Accountants* (Fifth ed.). South-Western College Pub. p. 33. ISBN 978-0-324-59455-3. Retrieved July 23, 2010.

19. "CPSC Safety Alert – Ingested Magnets Can Cause Serious Intestinal Injuries" (https://web.archive.org/web/20120303094112/http://www.cpsc.gov/CPSCPUB/PUBS/magnet.pdf) (PDF). U.S. Consumer Product Safety Commission. Archived from the original (https://www.cpsc.gov/CPSCPUB/PUBS/magnet.pdf) (PDF) on March 3, 2012. Retrieved July 23, 2010. "The U.S. Consumer Product Safety Commission (CPSC) is aware of at least 33 cases of children being injured from ingesting magnets. A 20-month-old died, and at least 19 other children from 10 months to 11 years old required surgery to remove ingested magnets."

20. Feds file suit against Buckyballs, retailers ban product (http://usatoday30.usatoday.com/money/industries/retail/story/2012-07-25/buckyballs-ban/56481316/1) , USA Today, July 26, 2012.

21. "CPSC Recall Snapshot" (https://web.archive.org/web/20161230090501/http://www.alston.com/Files/Publication/68cd9b0e-44e0-46d7-bcd8-69d930f70bfa/Presentation/PublicationAttachment/e8b8400f-13b8-479e-b103-6e2e7cb4f31d/CPSCRecallSnapshotDecember2016.pdf) (PDF). Alston & Bird. December 2016. Archived from the original (http://www.alston.com/Files/Publication/68cd9b0e-44e0-46d7-bcd8-69d930f70bfa/Presentation/PublicationAttachment/e8b8400f-13b8-479e-b103-6e2e7cb4f31d/CPSCRecallSnapshotDecember2016.pdf) (PDF) on 2016-12-30. Retrieved 2016-12-29.

22. Martin, Andrew (August 16, 2012). "For Buckyballs Toys, Child Safety Is a Growing Issue" (https://www.nytimes.com/2012/08/17/business/for-buckyballs-toys-child-safety-is-a-growing-issue.html) . *The New York Times*.

23. Buckyballs® High Powered Magnets Sets Recalled by Maxfield and Oberton Due to Violation of Federal Toy Standard (https://www.cpsc.gov/Recalls/2010/Buckyballs-High-Powered-Magnets-Sets-Recalled-by-Maxfield-and-Oberton-Due-to-Violation-of-Federal-Toy-Standard/) , Consumer Product Safety Commission, May 27, 2010.

24. Ahmari, Sohrab (Aug 30, 2013). "Craig Zucker: What Happens When a Man Takes on the Feds" (https://www.wsj.com/articles/SB10001424127887324108204579023143974408428) . *Wall Street Journal*. Retrieved September 1, 2013.

25. Buckyballs Safety Compliance (http://www.getbuckyballs.com/safety/retailers/) , Maxfield and Oberton.

26. "Safety Standard for Magnet Sets-Final Rule" (https://web.archive.org/web/20150528230700/http://www.cpsc.gov/Global/Newsroom/FOIA/CommissionBriefingPackages/2014/SafetyStandardforMagnetSets-FinalRule.pdf) (PDF). Archived from the original (https://www.cpsc.gov/Global/Newsroom/FOIA/CommissionBriefingPackages/2014/SafetyStandardforMagnetSets-FinalRule.pdf) (PDF) on May 28, 2015. Retrieved September 10, 2014.

27. "CPSC Warns High-Powered Magnets and Children Make a Deadly Mix" (https://www.cpsc.gov/en/Newsroom/News-Releases/2012/CPSC-Warns-High-Powered-Magnets-and-Children-Make-a-Deadly-Mix/) . Retrieved July 15, 2014.

28. Buckyballs fight back (https://www.washingtonpost.com/business/economy/buckyballs-fight-back/2012/08/02/gJQA1G9uSX_story.html) , The Washington Post, August 2, 2012.

29. "Gillibrand Urges Feds to Ban the Sale of Dangerous High-Powered Toy Magnets" (https://web.archive.org/web/20121212124355/http://www.gillibrand.senate.gov/newsroom/press/release/gillibrand-urges-feds-to-ban-the-sale-of-dangerous-high-powered-toy-magnets_) . Kirsten Gillibrand. June 19, 2012. Archived from the original (http://www.gillibrand.senate.gov/newsroom/press/release/gillibrand-urges-feds-to-ban-the-sale-of-dangerous-high-powered-toy-magnets_) on December 12, 2012.

30. "CPSC Sues Maxfield & Oberton Over Hazardous Buckyball" (https://web.archive.org/web/20120805044946/http://www.cpsc.gov/cpscpub/prerel/prhtml12/12234.html) . Archived from the original (https://www.cpsc.gov/cpscpub/prerel/prhtml12/12234.html) on August 5, 2012. Retrieved February 18, 2013.

31. "CPSC Sues Zen Magnets" (https://web.archive.org/web/20121028180610/http://www.cpsc.gov/cpscpub/prerel/prhtml12/12243.html) . Archived from the original (https://www.cpsc.gov/cpscpub/prerel/prhtml12/12243.html) on October 28, 2012. Retrieved February 18, 2013.

32. "Federal agency targets Denver magnet company with no history of injury" (https://web.archive.org/web/20121024024244/http://blogs.westword.com/latestword/2012/08/federal_agency_targets_denver.php) . Archived from the original (http://blogs.westword.com/latestword/2012/08/federal_agency_targets_denver.php) on October 24, 2012. Retrieved October 31, 2012.

33. Bellini, Jarrett (November 2, 2012). "Bye bye, Buckyballs" (http://www.cnn.com/2012/11/02/tech/web/apparently-this-matters-buckyballs/index.html?hpt=hp_c3) . *CNN*.

34. "10th Circuit Court of Appeals Opinion, Zen Magnets v. CPSC" (https://web.archive.org/web/20161212093121/https://www.ca10.uscourts.gov/opinions/14/14-9610.pdf) (PDF). Archived from the original (https://www.ca10.uscourts.gov/opinions/14/14-9610.pdf) (PDF) on December 12, 2016. Retrieved January 10, 2017.

35. "Recall Lawsuits: Adjudicative Proceedings" (https://www.cpsc.gov/en/Recalls/Recall-Lawsuits/Adjudicative-Proceedings/) . *U.S. Consumer Product Safety Commission*. Retrieved June 16, 2016.

36. "3/29/16 Update: Whoa. We won | Zen Magnets" (https://web.archive.org/web/20160606112956/http://zenmagnets.com/march-2016-update-whoa-we-won/) . *zenmagnets.com*. Archived from the original (http://zenmagnets.com/march-2016-update-whoa-we-won/) on June 6, 2016. Retrieved June 16, 2016.

37. "10th Circuit Court of Appeals Opinion, Zen Magnets v. CPSC" (https://web.archive.org/web/20161212093121/https://www.ca10.uscourts.gov/opinions/14/14-9610.pdf) (PDF). Archived from the original (https://www.ca10.uscourts.gov/opinions/14/14-9610.pdf) (PDF) on December 12, 2016. Retrieved January 10, 2017.

38. "How One Man's Quest to Save His Magnets Became a Massive Regulatory Battle" (https://www.huffingtonpost.com/entry/shihan-qu-zen-magnets-cpsc_us_599216a4e4b08a247276b0ea) . *HuffPost*. August 21, 2017.

39. Reeves, Patrick T.; Rudolph, Bryan; Nylund, Cade M. (2020). "Magnet Ingestions in Children Presenting to Emergency Departments in the United States 2009–2019: A Problem in Flux". *Journal of Pediatric Gastroenterology & Nutrition*. **71** (6): 699–703. doi:10.1097/MPG.0000000000002955 (https://doi.org/10.1097%2FMPG.0000000000002955) . PMID 32969961 (https://pubmed.ncbi.nlm.nih.gov/32969961) . S2CID 221885548 (https://api.semanticscholar.org/CorpusID:221885548) .

40. 30. ^Staff Briefing Package In Response to Petition CP 17-1, Requesting Rulemaking Regarding Magnet Sets. https://www.cpsc.gov/s3fs-public/Informational%20Briefing%20Package%20Regarding%20Magnet%20Sets.pdf?FKVcZpHmPKWCZNb7JEl6Ir0a31WV72PI

41. "Number of children swallowing dangerous magnets surges as industry largely polices itself" (https://www.washingtonpost.com/business/economy/number-of-children-swallowing-dangerous-magnets-surges-as-industry-largely-polices-itself/2019/12/25/77327812-2295-11ea-86f3-3b5019d451db_story.html?arc404=true) . *The Washington Post*. 2019-12-26. Archived (https://web.archive.org/web/20230611150132/https://www.washingtonpost.com/business/economy/number-of-children-swallowing-dangerous-magnets-surges-as-industry-largely-polices-itself/2019/12/25/77327812-2295-11ea-86f3-3b5019d451db_story.html?arc404=true) from the original on 2023-06-11.

42. "CPSC Issues Decision on Zen Magnets" (https://www.cpsc.gov/Newsroom/News-Releases/2018/CPSC-Issues-Decision-on-Zen-Magnets#:~:text=It%20is%20illegal%20under%20federal,any%20Zen%20Magnets%20and%20Neoballs) .

43. "Magnet safety" (https://www.canada.ca/en/health-canada/services/toy-safety/magnets.html) . November 15, 2010.

44. "Interim ban on novelty products with small magnets" (https://archive.today/20130219184421/http://www.fairtrading.nsw.gov.au/About_us/News_and_events/Media_releases/2012_media_releases/20120823_interim_ban_small_novelty_magnet_products.html) . Government of New South Wales – Fair Trading. August 23, 2012. Archived from the original (http://www.fairtrading.nsw.gov.au/About_us/News_and_events/Media_releases/2012_media_releases/20120823_interim_ban_small_novelty_magnet_products.html) on February 19, 2013. Retrieved January 6, 2013. "Mr Roberts said magnets from novelty products and executive toys had been swallowed by young children, while some older children and teenagers had swallowed magnets after using them as imitation tongue or lip piercings."

45. "VIC: Update: Permanent ban on small, high powered magnets" (https://www.productsafety.gov.au/content/index.phtml/itemId/997715) . Product Safety Australia. November 15, 2012.

46. "Ban on the sale of high powered magnet sets" (https://www.beehive.govt.nz/release/ban-sale-high-powered-magnet-sets) . New Zealand Government, January 23, 2013.

47. "DEMETER project" (https://etn-demeter.eu/project/) . *etn-demeter.eu*.

48. "REE-CYCLE project" (https://cordis.europa.eu/project/id/320915/reporting) . *cordis.europa.eu*.

Further reading

- Furlani Edward P. (2001). "Permanent Magnet and Electromechanical Devices: Materials, Analysis and Applications". Academic Press Series in Electromagnetism. ISBN 0-12-269951-3.

- Campbell Peter (1996). "Permanent Magnet Materials and their Application" (Cambridge Studies in Magnetism). ISBN 978-0-521-56688-9.
- Brown, D. N.; B. Smith; B. M. Ma; P. Campbell (2004). "The Dependence of Magnetic Properties and Hot Workability of Rare Earth-Iron-Boride Magnets Upon Composition" (https://web.archive.org/web/20120425082651/http://www.magnequench.com/assets/content/magnequench/mag_ref/mag_pps/pps_040701/IEEE2004_vMAG40.pdf) (PDF). *IEEE Transactions on Magnetics*. **40** (4): 2895–2897. Bibcode:2004ITM....40.2895B (https://ui.adsabs.harvard.edu/abs/2004ITM....40.2895B) . doi:10.1109/TMAG.2004.832240 (https://doi.org/10.1109%2FTMAG.2004.832240) . ISSN 0018-9464 (https://www.worldcat.org/issn/0018-9464) . S2CID 42516743 (https://api.semanticscholar.org/CorpusID:42516743) . Archived from the original (http://www.magnequench.com/assets/content/magnequench/mag_ref/mag_pps/pps_040701/IEEE2004_vMAG40.pdf) (PDF) on 2012-04-25.

External links

- *Standard Specifications for Permanent Magnet Materials* (http://www.allianceorg.com/pdfs/MMPA_0100-00.pdf) (Magnetic Materials Producers Association)
- Edwards, Lin (22 March 2010). "Iron-nitrogen compound forms strongest magnet known" (http://www.physorg.com/news188458077.html) . *PhysOrg*.